What you (probably) don't know about SOFIA

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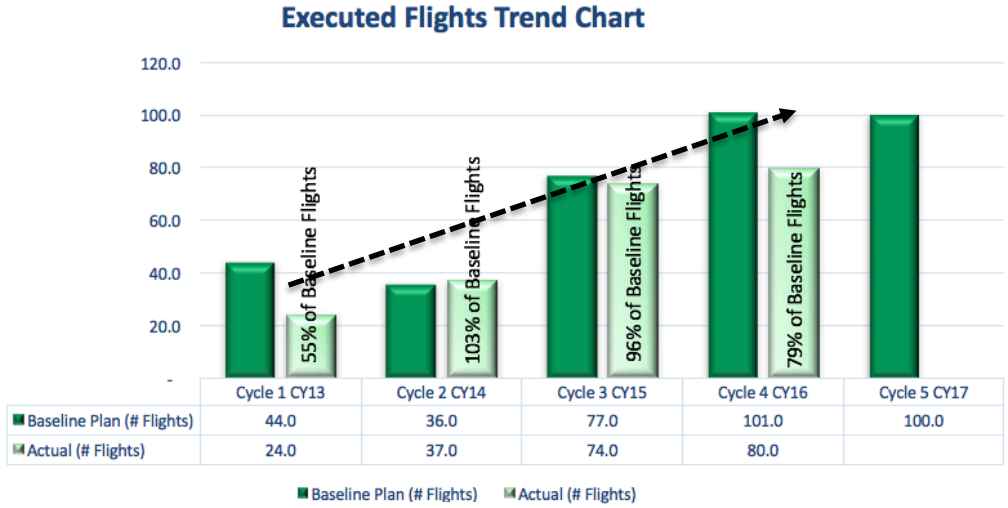
Harold W Yorke

Director, SOFIA Science Mission Operations

Setting the Stage

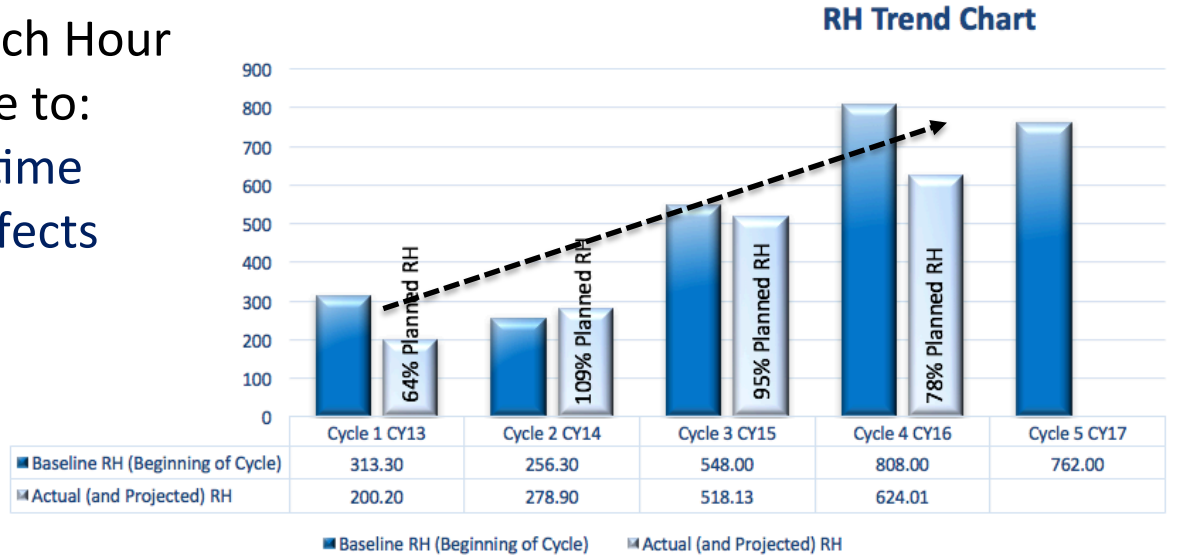
- SOFIA is not a space mission
  - Hardware repairs & updates are in principal possible on a relatively short time scale
  - New instruments can be added to address current relevant science questions
  - Several improvements to SOFIA operations since prime mission start 2014 have increased efficiency
  - SOFIA yesterday < SOFIA today < SOFIA tomorrow
- One goal of this workshop is to increase awareness of NASA's upcoming ROSES (step 1) call for the next SOFIA instrument(s)

SOFIA Operational Capacity Ramping Up!



- Program flight plans approaching full ops levels in Cycle 4 & 5 (dark bars)
- Program demonstrating increase in annual science flight execution and annual Research Hours (light bars)

- Planned Cycle 5 Research Hour estimate is reduced due to:
  - Low HAWC+ hold time (~5.5 hrs) which affects ~25% of Cycle 5
  - New upGREAT commissioning requirements



SOFIA's Longevity?

- SOFIA's prime mission is defined as five years from the end of the fiscal year during which SOFIA entered Phase E (i.e. 2014)
  - The prime mission phase ends September 30, 2019
- Long term plans for sustainment of the observatory shall preserve the capability for 20 years of operations
  - i.e. through May 2034
  - Continuation of mission depends on outcome of triennial Senior Reviews (required of all NASA missions)
- SOFIA is currently 40+ years old
  - SOFIA project has cannibalized several 747-SPs for spare parts (e.g. 12 jet engines on hand)

Cycle 5: SOFIA is operating at 100%

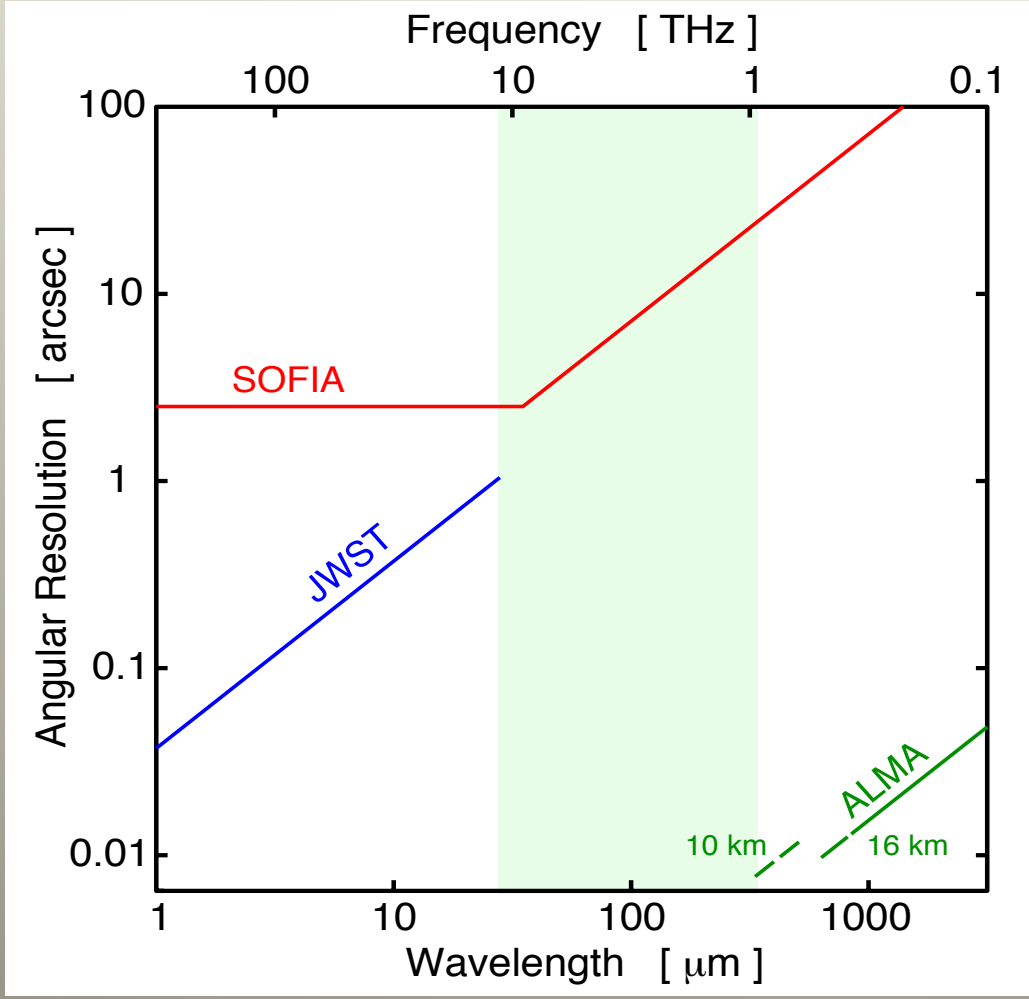
- 21 out of 21 planned SOFIA flights completed in Cycle 5
  - One contingency flight exercised after faulty smoke detector caused flight cancellation
- High number of contingency flights included in Cycle 5 plan: 20
  - Used if science flight has to be cancelled
  - Strategically placed in calendar to optimize utility
- Spare parts on hand should further reduce down times
  - A spare jet engine for SOFIA will be kept in New Zealand

Cycle 6: Further Optimizations Considered

- Multiple deployments to New Zealand with single instrument during period April - September
  - New Zealand offers greater flexibility for flight plans (fewer restricted zones; mostly over water)
  - New Zealand winter offers low water vapor (< 10 µm)
  - New Zealand offers access to Galactic Center and Magellanic Clouds
- Increased flight cadence: continuous 7 flights/week
- Quicker instrument swaps: 36 hours, instead of 3 days
- Miscellaneous optimizations of available time in air to increase time on science targets

SOFIA is important for FIR Science

SOFIA spans the Wavelength Gap between JWST and ALMA



JWST will offer unprecedented resolution and sensitivity from long-wavelength (orange-red) visible light to the mid-infrared (0.6 to 28 μm).

ALMA offers ~0.01 arcsecond resolution in its highest frequency bands. Band 10 (planned) will extend to 950 GHz (≈ 320 μm).

SOFIA is the only observatory that currently operates in 28-320 μm wavelength range.

There is great science potential for observing in ALMA-JWST gap.

Where is SOFIA's "Sweet Spot"?

- SOFIA is the only observatory in 28 µm – 320 µm range
- With its warm optics (~220K) SOFIA sensitivity is limited
  - 220K black body emissivity peaks at ~18µm
  - Optics, support structure, atmosphere contribute to background
    - Chop between target & empty sky
    - Subtract two large numbers for signal
    - Number statistics limit theoretical sensitivity
- Alternatively, reduce background radiation $F_\nu \Delta\nu$ by reducing bandwidth $\Delta\nu$ => high resolution spectroscopy
  - e.g. GREAT (heterodyne), EXES, HIRMES
  - Detailed studies of emission and absorption lines
  - Emission line maps

How do SOFIA's Instruments Measure up to the Sweet Spot?

- GREAT (**G**erman **RE**ceiver for **A**stronomy at **T**erahertz Frequencies)
  - PI class instrument (Rolf Güsten)
  - High resolution spectra (up to R=10^8)
  - Several frequency windows in the 1.5 – 5 THz range (60µm – 200µm)
  - Diffraction limited (14" at 158 µm)
  - Mapping speed of C+ line 50x faster than Herschel-HIFI due to multi-pixel array and improved noise temperature of receiver
  - The future: LFA-HFA (with dual cryocooler system), 4GREAT, M band, tbd additional bands

How do SOFIA's Instruments Measure up to the Sweet Spot?

- EXES (**E**chelon-**Cross**- **E**chelle **S**pectrograph)
  - PI class instrument (Matt Richter)
  - Operates in the 4.5 – 28.3 μm wavelength region
  - High (R ≈ 50,000 – 100,000), medium (R ≈ 5000 – 20,000) and low (R ≈ 1000 – 3000) spectral resolution
  - Not diffraction limited; reduced throughput to spectrometer because of small slit width wrt beam
  - JWST-MIRI: diffraction-limited, 5 – 28.5 μm, 1. photometric imaging, 2. coronagraphy, 3. single-source low-spectral resolving power (R ~ 100) spectroscopy, and 4. medium-resolving power (R ~ 1500 to 3500) integral field spectroscopy
  - EXES' future niche: high resolution mid-IR spectroscopy, bright sources

How do SOFIA's Instruments Measure up to the Sweet Spot?

- FORCAST (**F**aint **O**bject infra**R**ed **CA**mera for the **S**OFIA **T**elescope)
  - Dual-channel mid-infrared camera with 256x256 pixel detectors
  - Low resolution spectra R=200 through grisms
  - Wavelength range: 5µm – 40µm
  - Diffraction limited only at longest wavelengths
  - FORCAST's Future: JWST-MIRI covers 5µm – 28.5µm
    - HAWC+ covers 40 µm – 300 µm without spectroscopy
    - FIFI-LS covers 50 µm – 200 µm with spectroscopy
    - HIRMES will cover 25 µm – 122 µm with spectroscopy

How do SOFIA's Instruments Measure up to the Sweet Spot?

- FIFI-LS (Far Infrared Field-Imaging Line Spectrometer)
  - Dual integral field (5x5) spectrometers
    - short wavelength spectrometer (blue channel) operates at wavelengths between 50 µm and 125 µm
    - long wavelength spectrometer (red channel) covers the range from 105 µm up to 200 µm
  - Each channel has R~1000 – 2000
  - Pixel size limited (12" for red channel; 6" for blue)
  - Unlike Herschel-PACS, FIFI-LS has two gratings and can observe two wavelength ranges simultaneously and independently of each other
  - FIFI-LS' Future: FIFI-LS provides a unique capability in SOFIA's wavelength sweet spot; improvements via MKIDs?

How do SOFIA's Instruments Measure up to the Sweet Spot?

- FLITECAM (**F**irst **L**ight **I**nfrared **TE**st **CAM**era)
  - 1.0 – 5.5 µm photometer & medium resolution spectrometer
  - Set of filters for imaging
    - One filter wheel for J, H, K, L and M
    - Second filter wheel holds a selection of narrow-band imaging filters including Pa-α, Pa-α continuum, 3.07 µm H_2O ice, 3.3 µm PAH, L-narrow and M-narrow
    - Additional sorting filters for grism waveband selection
  - Three grisms provide medium resolution (R ≈ 1500) spectra over entire wavelength range
  - Future: FLITECAM will not be offered in Cycle 6 CfP

How do SOFIA's Instruments Measure up to the Sweet Spot?

- HIPO (**H**igh **S**peed **I**maging **P**hotometer for **O**ccultations)
  - Filter set includes the Johnson (UBVRI) and Sloan (u'g'r'I'z') filters as well as a filter for methane at 890nm
  - Although not offered in Cycle 5 Call for Proposals, HIPO will be used in the FLIPO configuration for the Triton occultation event in October 2017
  - Many of HIPO's capabilities are covered by the (visible light) focal plane imager, FPI+
  - Future: HIPO will not be offered in Cycle 6 CfP; HIPO useful to SOFIA for diagnostics (Shack-Hartmann)

How do SOFIA's Instruments Measure up to the Sweet Spot?

- FPI+ (**F**ocal **P**lane **I**mager-plus)
  - Standard tracking camera for the SOFIA telescope with 1024x1024 pixel science grade CCD sensor
  - It is a fast frame-rate imaging photometer in the 360-1100 nm wavelength range
  - Always available simultaneously with other instruments
  - Five Sloan Digital Sky Survey filters u', g', r', i', z' and a Schott RG1000 NIR cut on filter are available
  - Future: Many potential enhancements to optimize its use as occultation science instrument

How do SOFIA's Instruments Measure up to the Sweet Spot?

- HAWC+ (**H**igh-resolution **A**irborne **W**ideband **C**amera-plus)
  - Diffraction-limited imaging of polarized and unpolarized light in five broad bands 40 µm – 300 µm
  - Will be offered in Cycle 6 CfP with caveats
  - HAWC+'s Future: Unique capabilities: Far-IR imaging and polarization

How do SOFIA's Instruments Measure up to the Sweet Spot?

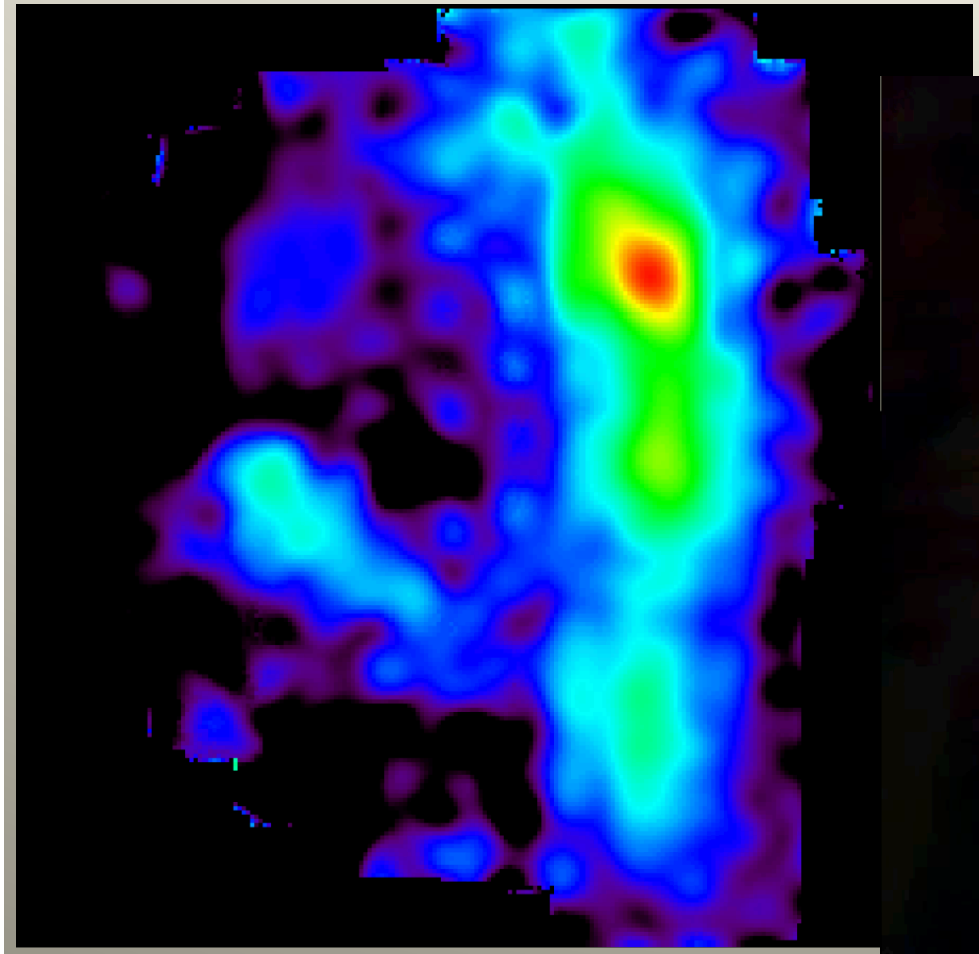
- HIRMES (High Resolution Mid-InfrarEd Spectrometer)
  - Wavelength range: 25µm – 122µm
  - Diffraction limited (or nearly so) over entire range
  - Variety of observing modes
    - Spectroscopy R=600 (low) 19,000 (mid) 100,000 (high)
    - Imaging spectroscopy mode: R ~ 2000 for a few selected emission lines
  - TES bolometers @ 0.1 K are background limited
    - >90% quantum efficiency over reasonably broad bands
  - Future: First light in 2019

How do SOFIA's Instruments Measure up to the Sweet Spot?

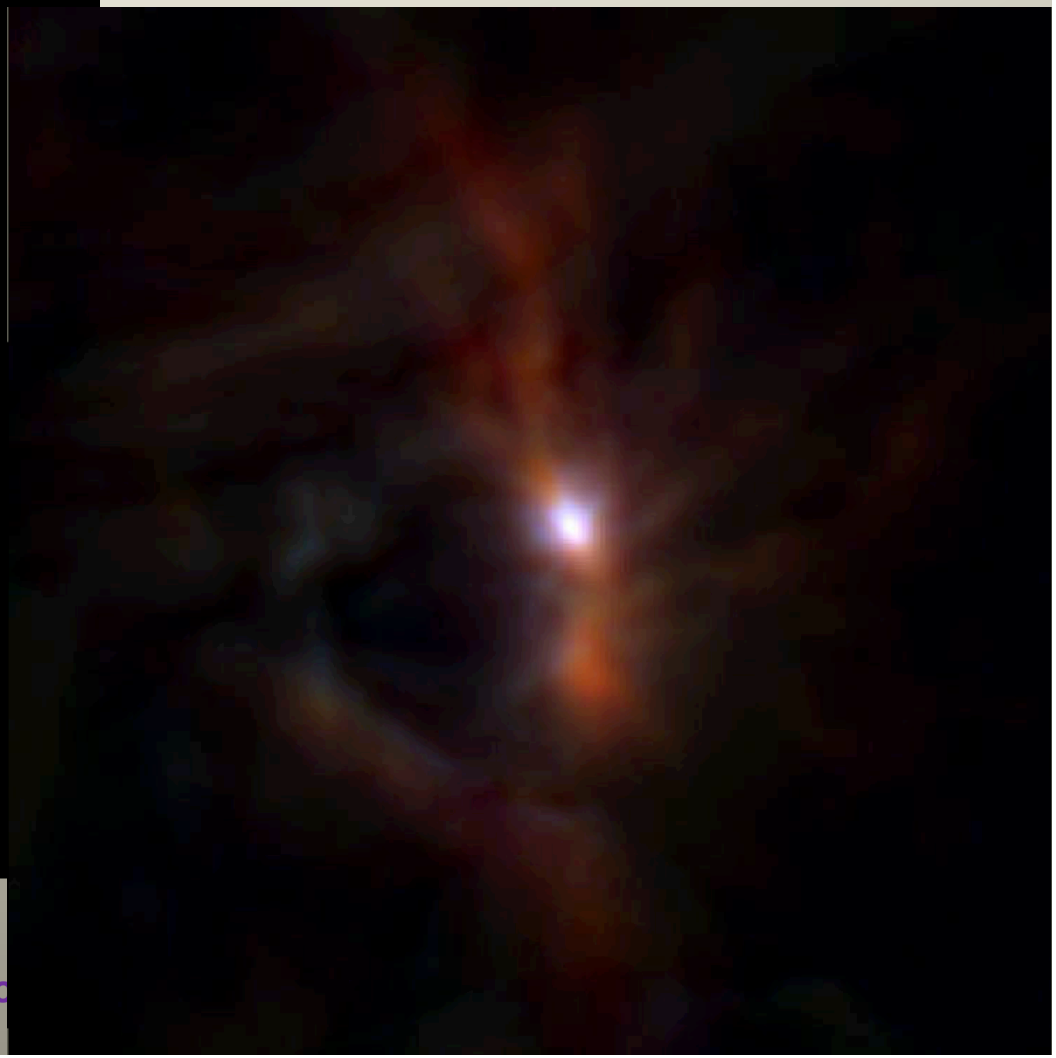
- NextGen (or Gen4)
  - Wavelength range and all other capabilities: tbd
  - Mass, power, data rate: see "Investigators Handbook"
  - Size/shape: has to get through the door and make the turn at the spiral staircase
  - NASA is planning a ROSES call in 2017

Orion observed with FIFI-LS and HAWC+

FIFI-LS (158 µm)



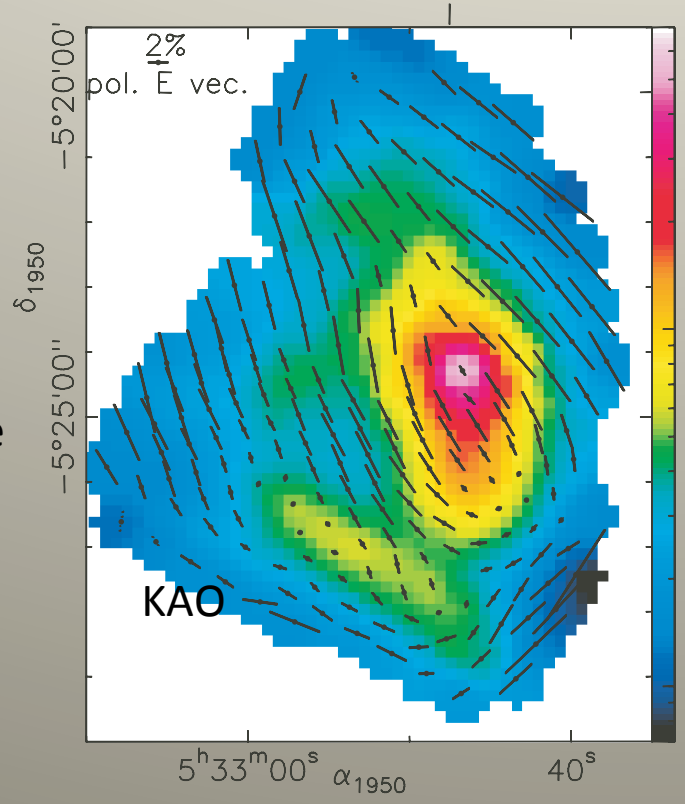
HAWC+ (Bands A [53 µm], C [89 µm], and E [214 µm])

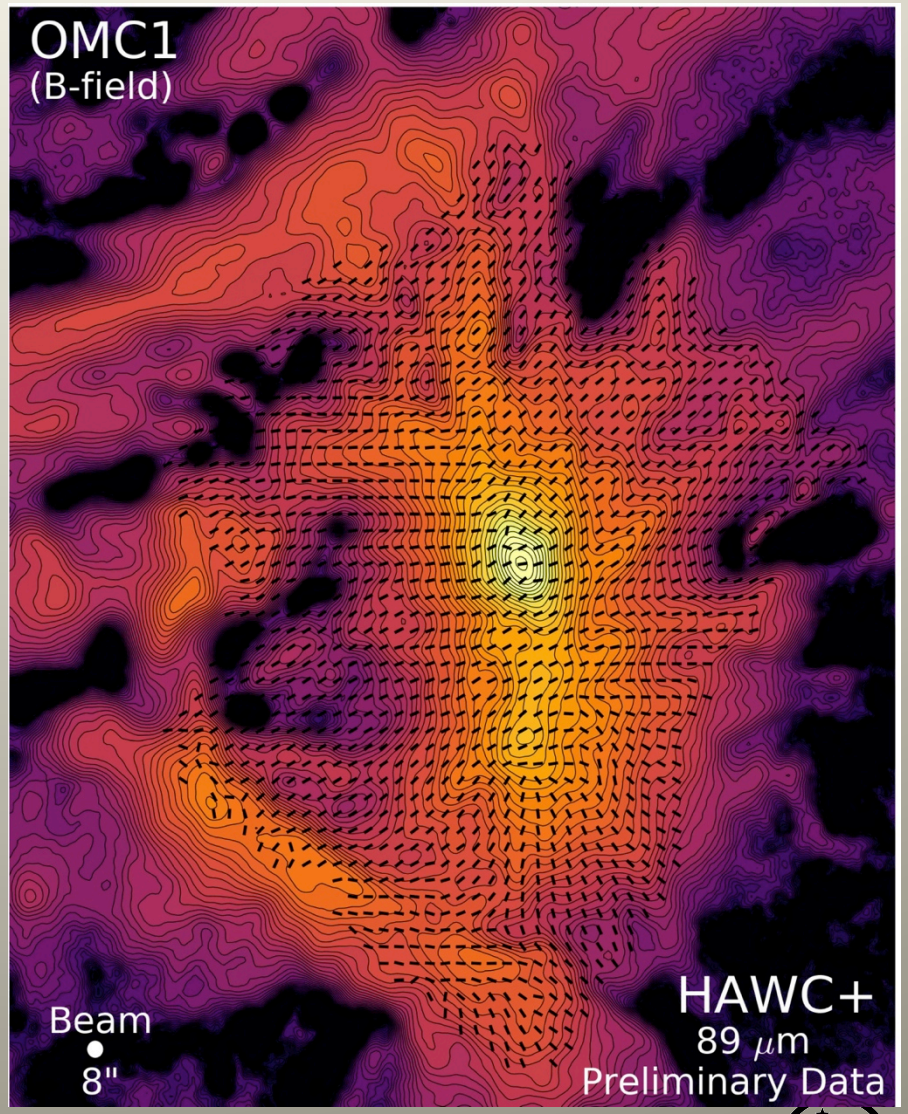


HAWC+ Science Highlight

Dust-induced polarization traces structure and strength of the interstellar magnetic field, which plays an important role in star formation.

Note: the KAO data show E-vectors; the SOFIA data show, rotated, B-vectors





Ask not what SOFIA can do for you, but what you can do for SOFIA

- It is time for every SOFIA aficionado to exercise his/her duty to vote.
- For the upcoming Senior Review of SOFIA, three metrics will be important: published papers, proposals for observing time, quality of proposals for the Gen4 instrument call
- If continuing SOFIA beyond 2019 is important to you, we are asking you to vote with your feet, namely by writing SOFIA papers, proposing to Cycle 6, proposing a new instrument or significant improvement to an existing one.
- Lots of papers need to be published asap, certainly before December 2017: "Vote early and vote often"


Thank You


http://www.sofia.usra.edu